

# MATERIAL CHOICE AND TRAVEL TIME IN ANCIENT POLYNESIA: AN EXPERIMENTAL PERSPECTIVE ON BASALT ADZE EXCHANGE<sup>1</sup>

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*"Prehistoric exchange cannot escape the need for the development of rigorous methods for linking the static material remains of the archaeological past to past dynamic behavior..."*  
(Torrence 1986:xi)

## INTRODUCTION

Exchange of materials between societies has long been a worldwide phenomenon (Anastasio 1972; Braun 1986; Brumfiel 1987; Carlson 1994; Hatch et al. 1990; Hayden and Schulting 1997; Hutterer 1977; Kirch 2000; Stark and Arnold 1997; Summerhayes 2001; Weisler 1997). As a fundamental focus of archaeological study for decades, researchers investigate the organizational attributes of prehistoric exchange through the recovered material patterns found in the networks' different stages; raw material procurement (Neff 1998; Weisler 1997), commodity production (Torrence 1986), product distribution (Renfrew 1969), utilization and consumption (Earle 1982). But in the last twenty years, researchers began to emphasize the role of acquisition (Glascok 2002), because geochemical techniques provide a scientific and quantifiable means to source materials, and have become increasingly accessible to archaeologists (Ericson and Baugh 1993). As a result, exchange research became more focused on the linking of two locales versus the study of cultural factors that perpetuate exchange networks. To address the cultural factors, this article investigates the economic processes found in basalt adze exchange networks of ancient Polynesia by conducting a simulative experiment on the relative utility of two exclusive material choices – basalt and shell. Then, the information is employed within a predictive optimal foraging model, where the results are tested against previously recorded archaeological data from West Polynesia.

Within Polynesia over the last three thousand years, insular chiefdoms produced elaborate social hierarchies requiring increased amounts of subsistence production to facilitate their higher populations and political complexities (Kirch 2000; Sahlins 1958). As an essential tool in their subsistence technology, islanders utilized adzes in felling trees, clearing land, shaping canoes, constructing homes, and other woodworking activities (Best et al. 1992; Buck 1930, 1950; Earle 1997; Green and Davidson 1969, 1974; Lass 1998; Leach and Witter 1990; Moir 1985; Salisbury 1962; Townsend 1969). Polynesian adzes were either manufactured out of basalt, a homogenous and often fine-grained volcanic rock, or out of shell, commonly made from bivalves such as the *Tridacna* species (Best et al. 1992; Moir 1985). Archaeologists often unearth these two material types together at islands, although, basalt's presence can be sporadic due to its unavailability on coral atolls. To explain its presence on atolls, basalt has been touted as a superior tool material for woodworking (Green and Davidson 1974), where high quality material is the reason

why islanders moved basalt adzes hundreds of kilometers from high volcanic islands to atolls over open ocean (Best et al. 1992). But, what is the authenticity of this assumption? Is there an actual economic superiority associated with basalt versus locally available materials, such as *Tridacna* shell? An uncritical understanding of subsistence requirements has clouded past interpretations of Polynesian exchange development.

The Pacific Ocean spans over 166 million square kilometers, covers a variety of major climatic zones, and contains over 25,000 islands and islets with differing landmasses, biodiversity and geology. Volcanic high islands and coral atolls describe the two general island types and major ecological differences found within Oceania. Atolls are composed of a narrow ring of low islets of humic soil and crushed coral encompassing a central lagoon, with a flat coral reef encircling the outside of the island (Best 1988). Volcanic rock is not native to an atoll and must be imported; although, clams can be routinely found in an atoll's shallow lagoon. Whereas, high islands of either 'continental' or 'oceanic' rock routinely have tool grade stone present, albeit rock quality varies greatly (Weisler and Sinton 1997:173; Dickenson and Shutler 2000:217-221). Confronted with this unequal distribution of important tool material resources in the Pacific, this article examines the documented exchange of basalt adzes in Polynesia (Best et al. 1992; Clark, et al. 1997; Di Piazza and Pearthree 2001; Sheppard, et al. 1997; Sinton and Sinton 1997; Walter and Sheppard 1996; Weisler 1993; Weisler, et al. 1994; Weisler and Kirch 1996; Weisler and Sinton 1997; Weisler 1998). Most pertinent to this research are the basalt adzes originating on Tutuila Island, which archaeologists traced to islands within Samoa, Fiji, Tokelau, Santa Cruz, Solomons, and Southern Cooks (Allen and Johnson 1997; Winterhoff 2003). Illustrating one possible factor in basalt tool exchange, Kaeppler (1978) describes a protohistoric trade network between Tonga, Fiji and Samoa as a social network or trade partnership for spouses and goods among these three cultural entities beginning in the mid 17<sup>th</sup> century and lasting into the historic period. Numerous researchers cite Kaeppler's 1978 review of this trade network as an archetypal example of exchange mechanisms (Best et al. 1992; Clark, Wright and Herdrich 1997; Earle 1997; Weisler 1997). Upon further study, the ethnohistoric evidence does not, however, provide a sufficient explanation for Tutuilian adzes found in earlier time periods and on other island groups outside the network such as Tokelau, Santa Cruz, Solomons, and Southern Cooks (Allen and Johnson 1997; Di Piazza and Pearthree 2001; Win-

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terhoff 2003). This article attempts to evaluate whether Tutuila adze trade was indeed a result of such social mechanisms (Kaeppler 1978; Weisler 1997) or more *ecologically* related ones (Earle 1997). This study calculates the utility of both clamshell and basalt as a tool for felling trees. The measurement of utility is accomplished by performing a simulative experiment assessing results of cutting rates. Then using each material's utility ratio, a predictive model of optimal foraging is implemented to examine issues of energy maximization in the different behavioral strategies required by either material.

## EXPERIMENTAL ARCHAEOLOGY

"The strength of imitative experimentation lies not in providing a final and single magical proof of a hypothesis, but rather in the elimination of improbable hypotheses and narrowing and sharpening the definition of the information" (Ingersoll, et al. 1977:xiv). Also, information on the manufacture and use of adzes in Polynesia is limited, due to the rapid and almost complete replacement of traditional tools with metal acquired after European contact (Bayman and Moniz Nakamura 2001:240; Buck 1930, 1950; Green and Davidson 1974:254; Lass 1998). Here, the lack of relevant ethnographic data makes the experimentation of those behaviors a necessity in accessing the reasoning behind material choices driving behaviors.

Previous comparative research on tree felling and material efficiency focused on the benefits of steel over stone tools (Salisbury 1962; Townsend 1969). Townsend's experiment assessed the relative efficiencies between stone and steel (1969). His research utilized native islanders to fell trees of varying sizes and hardness, while he timed the clearing with both materials. Relating time against the tree's circumference, Townsend found that steel was 4.7 times quicker than stone in felling trees. In complimentary results from an earlier ethnographic study, Salisbury (1962) concluded steel tools were three times as quick than stone adzes when clearing the same plot of land.

This article builds on this prior research by testing similar variables and using an experimental basis; however, it diverges by applying it to a prehistoric situation in which shell and stone were the sole choices. In addition, this experiment and analysis addresses a situation wherein an individual has a choice of utilizing either local or imported material as a tool, and what factors would influence such a decision. There could have been numerous social values at work in deciding which material to utilize, but values are difficult to assess archaeologically. Informed of this limitation, this study investigates significant factors in the past economic system. Important economic variables in making such a decision are the time-energies required to obtain the raw material and manufacture the tool, and then how the tool performs during use; its efficiency, durability, maintenance, costs and expected lifespan.

## POLYNESIAN ADZE TECHNOLOGY

### Acquisition

The *Tridacnidae* species of bivalves were utilized often as adze material in Polynesia. *Tridacna gigas* and *Tridacna maxima* are the two species most identified from shell adze assemblages (Moir 1985). As it relates to this study, their geo-

graphic distribution covers areas within island Melanesia, Micronesia and West and Central Polynesia. Complications on acquisition arise when discussing eastern and remote Polynesia, where cooler ocean currents impede reef growth and clam habitat.

In West Polynesia, islanders harvested them from inside lagoons exclusively or in tandem with fishing trips. Ethnographically, Goodwin observed clams being collected in lagoons on approximately one out of two daily fishing trips (Goodwin 1983:162-163); in addition, he stated that the meat inside of the clams produced protein for dietary consumption. Similarly, the efforts in prehistoric shell acquisition were embedded in complementary foraging activities, and the overall cost of acquisition thus reduced due to additional benefits of food production. Also, the overall size of the *Tridacna gigas* makes for abundant adze material. The species can grow up to 10 cm a year, and can reach ages of over one hundred years with sizes of 60 + cm in length. Ancient islanders acquired raw material for adze manufacture at a conservative rate of one shell adze per half day, based off Goodwin's observations and approximate adze sizes.

As for basalt, islanders from volcanic high islands needed a trip into the interior to obtain this material (Buck 1930). Archaeological research indicates that the relative proximity of quarries in Tutuila to habitation sites were very close, usually less than a kilometer in distance (Ayres and Eisler 1987; Clark, et al. 1997; Leach and Witter 1990; Winterhoff 2003). With prior knowledge and skill, selection and gathering of tool grade basalt could have happened quickly, and numerous blanks would have been acquired in an average day. A conservative rate of acquisition on a volcanic island estimates to one basalt adze blank per one fourth of a day of work (Leach and Witter 1990; Vial 1941; Winterhoff 2003).

Another component to basalt acquisition for this study is stone as an imported tool, where acquisition time needs to include transport time between islands. Using data from Irwin (1992:43-44), an average double-hulled Polynesian canoe could, in good weather, travel 100-150 nautical miles during a single day. It is assumed for the purpose of this study that the transport time between islands will roughly equal the time it takes atoll islanders to accumulate materials that cost the same amount of time-energies as the imported basalt adze brought from a high island.

### Manufacture

There is very limited data relating to the flaking qualities of clamshell in the Pacific; however, Cleghorn (1977) conducted a limited experiment on flaking *Tridacna* shell to analyze flaked shell tools from the Philippine Archipelago. His conclusions were that better flaking occurred from the use of a softer basalt hammer stone (3.5 Moh's hardness scale), fresh shell was easier to flake than fossilized specimens, and shells were probably initially broken for food extraction. Interestingly, the properties of the softer basalt are similar to coral, which also has a 3.5 on the Moh's hardness scale and was abundant on atolls.

Adzes manufactured out of *Tridacna* shell were often made into two types (Buck 1950; Moir 1985). Blanks coming from the thin outer portions of the bivalve produced smaller and flatter adzes with an overall quadrangular shape. Their

proposed function was for fine woodworking activities, like carving (Buck 1950). Adzes coming from the hinge area, where thicker accumulations of shell material were available, had a larger convex cross-section and length. Being larger, islanders utilized these adzes in felling trees and the rough shaping of canoes and house beams (Buck 1950). Clam sizes can allow for at least two blanks per shell or four per clam. Rough time estimation for the manufacture of a shell adze would be approximately one day, based on visual observations from this project. However, more research is needed to quantify this estimate.

While there is more ethnographic data on basalt adze manufacture, it is still sparse. Vial (1941:160) states that manufacture times for stone adzes in Papua New Guinea took half an hour to all day to chip out an adze blank, then polishing took up to three days for a high quality ceremonial adze. Also in Hawai'i, historic observations of adze manufacture stated that they ground and polished the adze over three to four days (Bayman and Moniz Nakamura 2001:240). However, an ordinary adze used for subsistence purposes would have taken less time, because of less accurate chipping and polishing. Such is the case for Samoan stone adzes; only the area around the cutting edge was polished on the majority of adze types (Green and Davidson 1969). Green and Davidson (1969) developed an adze typology for Samoa, where they recorded ten adze types with a few additional subtypes. Present in this adze typology are a variety of sizes, cross-sections, and overall shapes. The variety of types presents a situation where past woodworkers had specialized tools for different jobs; chiseling, carving or cutting. In addition, research on Samoan lithics indicates the preferred method of stone adze manufacture was first to knock off large flakes as blanks, which would have been easier to reduce into a preform, before the final grinding step (Leach and Witter 1990). For a subsistence tool, manufacture time for a stone adze would have averaged roughly two days, based on the combination of ethnographic and archaeological data.

#### Use

The adze was an important tool for ancient Polynesians. Using an adze, an islander could fell trees, make canoes, clear land, build homes, and create miscellaneous utilitarian and ceremonial objects (Buck 1930, 1950; Lass 1998). Archaeologically, adzes and their waste flakes compose the largest portion of artifact assemblages at prehistoric sites (Green and Davidson 1974). Although the static archaeological data in Oceania only hints at the dynamic past behaviors that produced them, ethno-archaeology and experimental archaeology attempt to fill in the gap (Binford 1981; Torrence 1986).

"The felling of a tree with a stone ax... has rarely been witnessed by ethnologists" (Carneiro 1979:21). While studying the Yanomamo of southern Venezuela, Carneiro conducted a replicative experiment to analyze how long it took a native Yanomamo using an 'ancestral stone axe' to cut down a tree (Carneiro 1979). In calculating the time required to fell a tree, he was able to attribute his results to other trees by creating a mathematical formula to determine the cutting time required by the amount or volume of wood needed to be removed for the tree to fall (Figure 1). While conducting a separate experiment on felling a tree, my study relied on

$$V = \pi h(D^2 - d^2)/8$$

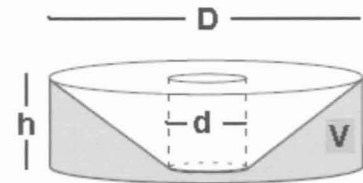


Figure 1. Carneiro's volume equation and associated schematic (1979).

Carneiro's mathematical equations to calculate comparable cutting and wear rates.

A tool's lifespan is the cumulative amount of work it is capable of finishing, beginning at its inception until its discard. Admittedly, adzes are known to have different uses (i.e. heirloom objects) that would extend their lives longer than its functional classification (Sheppard, Walter and Parker 1997). For this experiment, lifespan will stay with a more simple definition, total use for its original function as a woodworking tool.

#### Maintenance

Tool maintenance occurred regularly during and between uses. Chips along cutting edges accumulated over time thus retarding the cutting efficiency of the tool. Maintenance required re-sharpening of the cutting edge and was accomplished by polishing the edge against a grinding stone until the needed blade was produced. Townsend (1969:201) found that the Heve tribe of New Guinea dulled stone adzes after 3 hr and 49 minutes, and sharpening a stone adze took them roughly an hour.

#### Hafting and Lashings

Hafting an adze to a handle is an integral part of the subsistence technology. Correct hafting can add additional leverage, increased force and a stable striking edge at impact, which are attributes that greatly help in felling trees. Buck (1930) discusses three elaborate lashing techniques on Samoan adze handles, but a multitude of correct application methods would have been available in past societies. It is assumed that ancient tool users utilizing either basalt or shell adzes would have had equal knowledge of hafting, thus for this experiment this data should cancel itself out.

#### METHODOLOGY

To calculate a material's utility in tree felling and, to a greater extent, general wood working, efficiency measures need to be accounted for by experiments. For this paper, efficiency will be defined as the number of cubic centimeters cut within a minute. To collect this data, an experiment was conducted with every attempt to replicate objects and conditions similar to the past ones being tested.

#### Equipment Used for Experiment

To conduct an experiment that examines tool material's efficiency, one shell and one stone adze were manufactured with approximately equal volume and cutting edge (Figure 2). The shell adze had a length of 8.5 cm, a cutting width of 4.0 cm, 1.9 cm thickness, a 70 degree bevel angle, and weight of



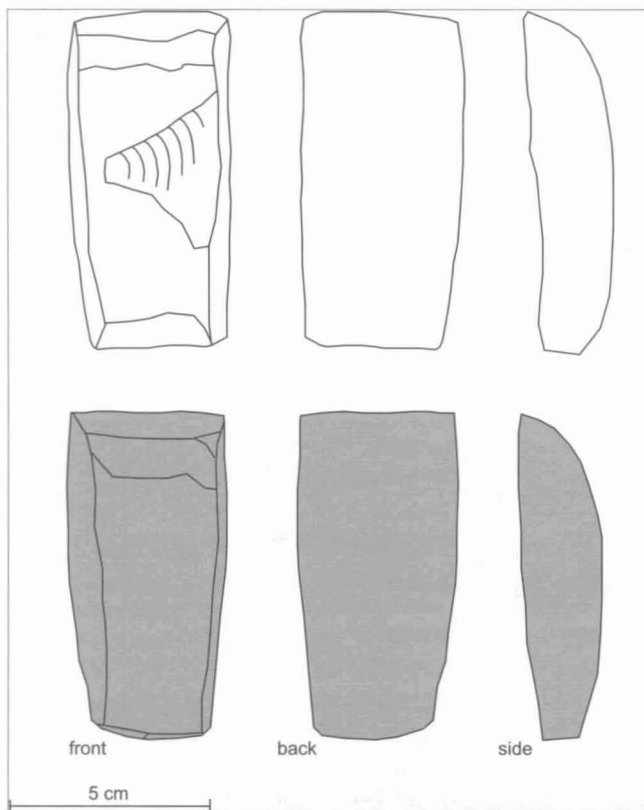


Figure 2. The front, back and side views of the shell (on top) and basalt (on bottom) adzes used in the experiment.

136.5 grams. The shell adze was made from a fresh *Tridacna gigas* shell measuring 25 cm by 20 cm. Due to limitations in acquiring basalt from Tutuila, an adze was made from local medium quality basalt (Springfield Quarry, Oregon). The basalt adze measured 8.4 cm in length, a cutting width of 3.9 cm, 2.1 cm thickness, 70° bevel angle and weighed 158.2 grams.

Physical property analyses were conducted on samples of Tutuilan basalt, the local basalt used in this experiment, and clamshell, so an assessment of their tensile strengths could be examined and compared (Table 1). An object's tensile strength is the maximum amount of stress it can take prior to the object breaking. Tensile strength is measured in force per unit area or pounds per square inch (psi) by a Point-Load Tester. The machine concentrates an increasing load on the sample, while the surrounding loading frame measures the force applied. The information has significant implications for material choice, particularly to its durability during use. The

Table 1. Tensile Strength Measurements.

Material	Tensile Strength (psi)
<i>Tridacna Gigas</i> Shell Fiji Islands (n = 6)	4146 (median)
Medium Quality Basalt Springfield Quarry, Oregon (n = 4)	3080 (median)
High Quality Basalt Malaeloa Quarry, Tutuila (n = 1)	4402

Malaeloa Quarry sample has a 30% greater tensile strength than the basalt used in the experiment, and has a strength rating in the upper range of basalts (Logan, personal communication). The surprising results from the *Tridacna* shell come from the extremely dense nature of the shell's crystalline structure, which outweighs the differences in strength between shell's carbonate and basalt's silicate composition (ibid.).

Polynesian canoes were often made from large breadfruit trees (*Artocarpus altilis*). The unavailability of breadfruit trees at the locality of the experiment required an adequate replacement, so the simulation study could be as accurate as possible. A local softwood was selected with a similar specific gravity. Breadfruit has a specific gravity of 0.5 (Donnegan et al. 2001). Douglas Fir has a specific gravity of 0.45, and was chosen as a proxy species (Briggs 1994). For the experiment, two Douglas Fir trees with a 20 cm diameter trunk were selected.

#### Material Efficiency Experiment

To assess a tool material's efficiency, an experiment was performed similar to one conducted in the Amazon by Carneiro (1979). His ethno-archaeological study involved a local informant, who was timed as he cut down a tree using a stone axe. For my experiment, three volunteers, with varying levels of expertise, were asked to cut down a tree utilizing each adze. A conscious effort was made by each volunteer to vary their style of chopping during the experiment (two handed, one handed, forceful chop and cleaning cuts) so to help negate a bias from a possible learning curve between the two experiments. At the beginning and end of each experiment, each adze was measured for wear and the tree was measured for volume of wood cut. Time was subtracted when adjustments were needed to re-haft or a volunteer needed to rest. Totaling the cumulative timed sessions per adze material, an average cut rate was created. The cut rate is not an absolute rate comparable to prehistoric woodworkers, but a relative rate that can be compared between materials.

#### Mathematical Analysis

To analyze the results of the above experiment, a foraging choice model was created to predict the behavioral decisions of ancient islanders. The model is graphically represented in a statistical bi-plot, where the two axes of the graph report the measured utilities of each substitutable material. This is based on the assumption that, within an economic system, past choices were made to maximize one's benefits and to minimize one's losses. As a result, a person will implement the group of choices that will create the most utility. Utility is defined as "the level of satisfaction derived from the consumption and is determined inductively by measuring what people maximize (Kaplan and Hill 1992)." To create an optimal foraging model, two factors are needed: 1) total benefit available from the use of either material, and 2) time cost of each resource or the price of commodities – the income that must be expended to acquire a given amount (Kaplan and Hill 1992; Hill 1988).

## RESULTS

### Efficiency

The stone adze was able to fell a tree with a volume of 2646.2 cm<sup>3</sup> in 76 minutes. The basalt material's relative cut rate calculates to 34.82 cm<sup>3</sup> per minute. It required 83 minutes to fell a tree utilizing the shell adze with a volume of 2029.3 cm<sup>3</sup>. This calculates to a 24.45 cm<sup>3</sup> per minute cutting rate. In order to evaluate whether this difference would have influenced decisions on what material type to use, one needs to look at adze efficiency performs in different situations. By inserting the cut rates of each material derived from experiment into the equation provided by Carneiro (1979), times (in hours) can be calculated for the felling of a variety of tree sizes (Table 2).

Table 2. Postulated fell time for various diameters of trees.

Tree Diameter cm	Approximate Volume of Material Cut From Tree for Fell cm <sup>3</sup>	Shell Adze Calculated Time for Fell hours	Basalt Adze Calculated Time for Fell hours
20	2100	1.43	1
30	4700	3.20	2.25
40	8400	5.73	4.02
50	13,000	8.86	6.22
60	18,800	12.82	9

### Durability

While efficiency is one variable that needs to be considered with decisions, durability must also be considered. Following the experiments, the adzes exhibited notable wear along their cutting edges. There was visible chipping on both adzes' edges, where basalt and shell had roughly equal amounts of wear. By combining the experimental results with Townsend's (1969) data from the Heve, a basalt adze needs to be re-sharpened after every 3.81 hours of cutting; re-sharpening takes an hour and approximately ½ cm is removed from the tool's length. Based on the similar tensile strengths and in field observation, *Tridacna* shell would have a comparable re-sharpening schedule.

Durability of the materials becomes a significant factor, when you combine a material's cut rate, a material's wear rate and its sharpening rate while felling a tree larger than 20 cm in diameter. For a 20 cm diameter tree, the time difference in felling is roughly 40 minutes between basalt and shell adzes, but when cutting down a 60 cm diameter tree, the basalt adze took eleven hours and *Tridacna* shell required 15.82 hours. This discrepancy between basalt and shell has a major impact on the effective life span of the tool. A tool's lifespan was calculated to be the length of use time necessary to wear the tool to half of its original size. The two manufactured adzes had a total length of 8.5 cm with a hypothetical discard length at 4.25 cm. The tool's overall effectiveness was then calculated by estimating the amount of wood volume cut before the tool was exhausted. Calculating the overall number of sharpening periods as eight and combining the material's efficiency, the

research indicate a total lifespan of shell adzes at 39,609 cm<sup>3</sup> of wood volume and 56,408.4 cm<sup>3</sup> for basalt adzes. The results suggest that the medium basalt has a 30 percent longer lifespan than *Tridacna* shell, which may be a product of the materials' densities. When looking at time-energies as they relate to work productivity, the total productive lifespan for basalt is 3 days (8 hr/day) while shell equals 2.1 days.

### Overall Utility

To calculate a material's overall utility, an estimate of all time-energies expended for each behavioral decision are needed, where the total productive lifespan is divided by the cost of acquisition, manufacture and maintenance (Table 3).

Table 3. Experimental and Estimated Results Per Adze on the Overall Utility of Shell and Basalt as a woodworking Tool.

	Acquisition day	Manufacture day	Maintenance day	Use day
basalt	0.25	2	0.33	3
shell	0.5	1	0.33	2.1

utility = benefit/cost = use/(acquisition + manufacture + maintenance); basalt utility = 1.16; shell utility = 1.15

As a woodworking tool, basalt has a utility of 1.16 and shell has a utility of 1.15. Based on the assumption that both materials are available, basalt has a slightly higher utility rating than shell. However, what happens when basalt adzes must be imported from another island?

### Predictive Model

Given that the majority of adzes in ancient Oceania are tied to subsistence practices, a simple foraging model was employed to examine decisions that would maximize an islander's long-term net rate in an economic system. According to Smith and Winterhalder, "simple tools are a necessary tool for the analysis of complex systems" (1992:23). The model has three parts: 1) the decision to acquire local shell or import a basalt adze; 2) the currency of time-energies found in each material's utility; and 3) the constraint of distances required to import an adze in the insular environment of the Pacific. To create predictions of basalt adze exchange, I utilized optimal foraging models to examine the relative utilities of basalt compared to shell as the distance from which basalt is acquired increases. Time, as related to travel distances between islands, was used to explore the differences in utility ratios of both materials (Figure 3). Based on averaging the costs and benefits of both basalt and shell, the mean foraging return rate (represented by a dotted line in the models) provides the selection parameter for the optimal material. When the utility of a material exceeds the mean foraging return rate, that material will be chosen. In model A, the utility of basalt and shell are based on the availability of each item on the same island. In model B, basalt is located on another island, thus basalt's utility is lower than the mean return rate, because of the additional cost of importing it over a half a day voyage. Then in models C and D, basalt adzes are ranked considerably lower in comparative utility when it is necessary to ship basalt for one and two days, respectively.

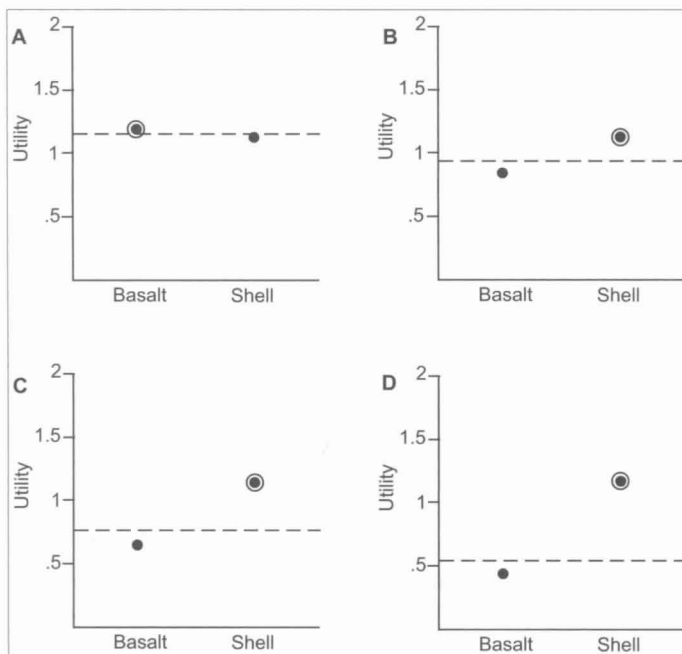


Figure 3. Results from experiment charting the optimal choice based on utility and travel time between islands, circled dot indicates optimal choice; A) materials found on the same island; B) importing basalt takes 0.5 day; (C) importing basalt takes 1 day; D) importing basalt takes 2 days.

## DISCUSSION

### Testing the Model in the West Polynesia Region

To test the proposed model, the islands of Tokelau and Samoa were selected to compare against the experimental results for five major reasons: 1) the distance between the archipelagos is roughly a two to three day voyage (Irwin 1992); 2) the recorded presence of Tutuilan adzes found on Tokelau (Best et al. 1992; Winterhoff 2003); 3) *Tridacnid* species were present on Tokelau in prehistory (Moir 1985); 4) Tokelau lies outside the Fiji-Tonga-Samoa Trade Network (Kaeppeler 1978; Weisler 1997); and 5) the volcanic islands of Samoa, especially Tutuila, had major production zones for basalt adzes in prehistory (Ayres and Eisler 1987; Best et. al. 1992; Buck 1930; Clark, et. al. 1997; Weisler 1997; Winterhoff 2003).

Tokelau is composed of three coral atolls, Fakaofu, Nukunomu and Atafu, located approximately 450 kilometers north of Tutuila. At Tokelau, prosperous settlements would have first occupied these atolls at 1000 BP coming from western Samoa. Tokelau lacks native basalt for adze manufacture, and would have either utilized local clam shell or imported stone adzes.

Simon Best (1988) conducted initial surveys on all three of the islands and excavations (a total of 66m<sup>2</sup>) on Fakaofu and Atafu. His discussion of recovered artifacts was preliminary, but qualitative conclusions can be drawn. As relating to adze material composition "[s]hell adzes were the most numerous artifacts found, both in surface collections and from excavations" (Best 1988:110), and, stone adzes and fragments were found in only limited quantities. Comparing Tokelau's archaeological data to the results of the predictive model, there is a tentative positive correlation between the experiment and the past material record found in the archipelago.

Although there were small numbers of basalt tools recovered in excavation, the majority of tools were comprised of shell. This evidence provides support for the optimal strategy presented in this study. The presence of limited amounts of basalt adzes may be explained as a result of disaster relief from Samoa. After large tropical storms or hurricanes, Tokelau's lagoon resources would have been greatly ravaged by heavy wave action. This situation would have required imported adzes despite the models' predictions, due to the needed rebuilding of residential structures and land clearing without local resources to draw upon.

## FURTHER DIRECTIONS FOR THE RESEARCH

To further test the proposed model, the island of Upolu in the Samoan Archipelago was also chosen to contrast the results of optimal distance for four major reasons: 1) Tutuila is roughly 40 nautical miles east of Upolu or less than a half day voyage, thus creating a positive prediction for the economic exchange of basalt adzes; 2) based on the archaeological record, Upolu and Tutuila, as with the rest of the archipelago, developed jointly into traditional Samoa at around 1700 BP (Ayres and Eisler 1987); 3) no archaeologically recorded basalt quarries have been documented on Upolu, and 4) there has been documentation of a Tutuilan adze recovered in western Samoa (Best et al. 1992).

Based on the foraging models, if the superiority of basalt adzes as subsistence tools were the basis for exchange in Polynesia, then the resultant sphere of interaction would have been relatively small or nonexistent. As Upolu lies within a positive distance for basalt adze exchange from Tutuila, Tutuilan basalt should be found in substantive number on Upolu, complementing their local, lower quality basalt. To compare the archaeological record to the results from the predictive model, a comparison of lithic production of the two islands is necessary (Table 4). Even when incorporating the differences in excavation techniques, site types and the amount excavated, Tutuilan sites contain significantly higher amounts of waste flakes compared to the number of adzes and adze fragments found at each site. These high production levels at workshop sites in Tutuila posit the likelihood of adze manufacture for both local subsistence use and inter-island exchange. However, greater numbers of excavated adzes found on Upolu and other archipelagoes need to be geochemically sourced to more accurately evaluate the ultimate distribution of Tutuilan basalt adzes.

From this research, intra-archipelago interaction would be the most likely outcome if acquiring basalt for subsistence tools were the sole mechanism for exchange. As for the noted high production levels of adze manufacture on ancient Tutuila (Winterhoff 2003); this study predicts that the majority of these products will be located on either Upolu or Savai'i in the western portion of Samoa rather than outside the archipelago.

Exchange as a set of behaviors is not directly observable in the archaeological record, and archaeologists need to create and test methodologies to connect exchange processes with the material record (Torrence 1986). The preliminary results presented here do not presume to allow us to reconstruct ancient behaviors, but it represents an attempt to construct a methodology to measure exchange. By comparing the utility

Table 4. A Comparison of Basalt Adze Production on Upolu, Samoa and Tutuila, American Samoa.

Site Name	Flakes	Site Function	Age	Number of Adze	Waste
<b>Upolu</b>					
Folasa-a-lalo		Inland Residential Site	Prehistoric	18	4
Leuluasi		Inland Residential Sites	Historic/Prehistoric	18	87
Puna		Inland Earthen Mound	Prehistoric	7	25
Sasoa'a		Inland Residential Site	Historic/Prehistoric	58	105
SuLu53		Inland Star Mound	Prehistoric	13	271
SuLo01		Coastal Midden	Historic/Prehistoric	3	90
Vailele		Coastal Earthen Mounds	Prehistoric	47	99
<b>Tutuila</b>					
Alega		Coastal Workshop Site	Prehistoric	5	2498
'Aoa		Coastal Residential Site	Prehistoric	12	3559
Malaeloa		Inland Workshop Site	Prehistoric	8	4869
Maloata		Coastal Residential Site	Prehistoric	10	711
Tataga-Matau*		Inland Workshop Site	Prehistoric	2	3099

(data for Upolu sites were collected from Green and Davidson 1969 and 1974); (data for Tutuila sites were collected from Clark 1992; Clark and Michlovic 1996; Winterhoff 2003; Ayres and Eisler 1987; Best, et al, 1998) \*Star Mound Terrace

and the physical properties of each material, one can directly investigate consumption requirements within an economic system, and indirectly investigate the production rate required to fulfill them. Further work is required to ascertain consumption rates for adzes in an island society; however, if one were to look at the household as the relevant archaeological unit in consumption (Green 1993) and calculate the amount of work hours needed to provide all the woodworking activities for a single generation. Then, one could divide the total number of work hours required by the work hours available per adze. Then, this number (times the number of generations present) should roughly equate to the actual number of adzes present in the archaeological record sans additional depositional anomalies.

A fruitful extension of this research would be to examine additional island groups in Oceania with unique acquisition environments and to test the utilities of different adze materials available for consumption within those island groups. Future experiments will require additional effort to examine the cutting rates and durability of materials. The results from this experiment create a basis of comparison, but more simulative work can only enhance the validity of the approach. Moreover, there are unresolved issues regarding the wide variety of shell and basalt found and used throughout the Pacific.

Testing of archaeological samples can also provide valuable information on the tensile strength of each material, which would document the significant impacts of the durability of each material and thus its utility as a subsistence tool. Additional work may highlight that physical properties, alone, provide adequate measures for both a material's efficiency and durability, thus replacing the need for individual and time-consuming experiments with data that is easily repeatable and quantifiable.

## CONCLUSIONS

Citing Davidson (1971:68-69), Roger Green states that relying simply on the clam shell for tool material was not a feasible alternative. As he wrote thirty years ago, "[a]n unstated assumption that seems to have prevailed with respect to materials suitable for Polynesian adzes is that the materials most widely and frequently used represent a choice that was almost entirely the result of cultural preference" (Green and Davidson 1974:142). His argument was that exchange between islands negated environmental discrepancies when it came to tool materials. But, based on the results of this study, the material for adzes was not a reason for continued exchange in Polynesia, and other materials, such as *Tridacna* shell, were a viable alternative as a locally available material.

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